PHYS 314: THERMODYNAMICS & STATISTICAL MECHANICS

NOTES:

- ❖ This examination has 5 questions on 4 pages.
- ❖ Question Q1 is of 30 marks and is compulsory. Each of the other four questions (Q2 through Q5) has 20 marks and you choose any 2 of them.
- ❖ There are 70 possible marks for this examination.
- ❖ Clarity and organization of the answers are important.
- ❖ Duration: 2 Hours

Q1

a) Define the following terms: heat engine; heat pump; thermal efficiency; Carnot cycle; entropy. **5 marks**

b) Explain the following processes: Adiabatic; Cyclic; Reversible; Isothermal; isobaric. **5 marks**

c) State the **first** and **second** laws of thermodynamics. **2 marks**

d) An ideal gas absorbs 5.00×10^3 J of energy while doing 2.00×10^3 J of work on the environment during a constant pressure process. Compute the change in the internal energy of the gas. **3 marks**

e) A block of ice at 273 K is put in thermal contact with a container of steam at 373 K, converting 25.0 g of ice to water at 273 K while condensing some of the steam to water at 373 K. Find the change in entropy of the (i) ice (ii) steam (iii) Universe. **6 marks**

f) During one cycle, an engine extracts 2.00×10^3 J of energy from a hot reservoir and transfers 1.50×10^3 J to a cold reservoir. Calculate the (i) thermal efficiency of the engine (ii) work this engine does in one cycle (iii) average power the engine generates if it goes through four cycles in 2.50 s. **9 marks**

Q2

a) In a car engine operating at a frequency of 1.80×10^3 rev·min^{-1}, the expansion of hot, high-pressure gas against a piston occurs in about 10 ms. Because energy transfer by heat typically takes a time on the order of minutes or hours, it's safe to assume little energy leaves the hot gas during the expansion. Find the work done by the gas on the piston during this adiabatic expansion by assuming the engine cylinder contains 0.100 moles of an ideal monatomic gas that goes from 1.200×10^3 K to 4.00×10^3 K, typical engine temperatures, during the expansion. **4 marks**

b) A quantity of 4.00 moles of a monatomic ideal gas expands from an initial volume of 0.100 m^3 to a final volume of 0.300 m^3 and pressure of 2.5×10^5 Pa (see Fig. 1). Compute the (i) work done on the gas (ii) change in internal energy of the gas (iii) thermal energy transferred to the gas.

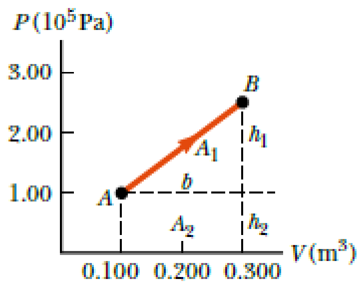

Fig. 1

8 marks

c) A 2.00-L container of leftover soup at a temperature of 323 K is placed in a refrigerator. Assume the specific heat of the soup is the same as that of water and the density is 1.25 kg·m^{-3}. The refrigerator cools the soup to 283 K.

i. If the COP of the refrigerator is 5.00, find the energy needed, in the form of work, to cool the soup. **4 marks**

ii. If the compressor has a power rating of 200 W, for what minimum length of time must it operate to cool the soup to 283 K? (The minimum time assumes the soup cools at the same rate that the heat pump ejects thermal energy from the refrigerator.) **4 marks**

Q3

(a) Suppose a system of monatomic ideal gas at 2.00×10^5 Pa and an initial temperature of 293 K slowly expands at constant pressure from a volume of 1.00 L to 2.50 L. Find the (i) work done on the environment (ii) change in internal energy of the gas (iii) thermal energy absorbed by the gas during the process (iv) thermal energy absorbed. **12 marks**

(b) A monatomic ideal gas has a temperature $T = 3.00\times10^2$ K and a constant volume of 1.50 L. If there are 5.00 moles of gas: (i) How much thermal energy must be added in order to raise the temperature of the gas to 3.80×10^2 K? (ii) Calculate the change in pressure of the gas, ΔP. (iii) How much thermal energy would be required if the gas were ideal and diatomic? **8 marks**

Q4

(a) A heat engine contains an ideal monatomic gas confined to a cylinder by a movable piston. The gas starts at A, where $T = 3.00\times10^2$ K. (See Fig.2.) The process $B \rightarrow C$ is an isothermal expansion.

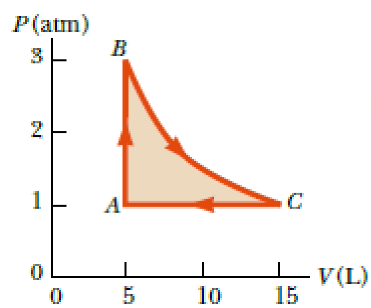

Fig. 2

Find (i) the number n of moles of gas and the temperature at B. (ii) ΔU, Q, and W for the isovolumetric process $A \rightarrow B$. (iii) The net change in the internal energy for the complete cycle (iv) the thermal energy Q_h transferred into the system (v) the thermal energy rejected, Q_c, the thermal efficiency, and net work on the environment performed by the engine. **20 marks**

Q5

(a) With suitable diagrams, describe the operation of a Carnot engine through one cycle and derive an expression for its thermal efficiency. **10 marks**

(b) A steam engine has a boiler that operates at 5.00×10^2 K. The energy from the boiler changes water to steam, which drives the piston. The temperature of the exhaust is that of the outside air, 3.00×10^2 K. (i) What is the engine's efficiency if it's an ideal engine? (ii) If the 3.50×10^3 J of energy is supplied from the boiler, find the energy transferred to the cold reservoir and the work done by the engine on its environment. **6 marks**

(c) A freezer is used to freeze 1.0 L of water completely into ice. The water and the freezer remain at a constant temperature of $T = 0$ °C. Determine the change in entropy of the (i) water (ii) freezer. **4 marks**